Measurements of γ from tree-level decays at LHCb

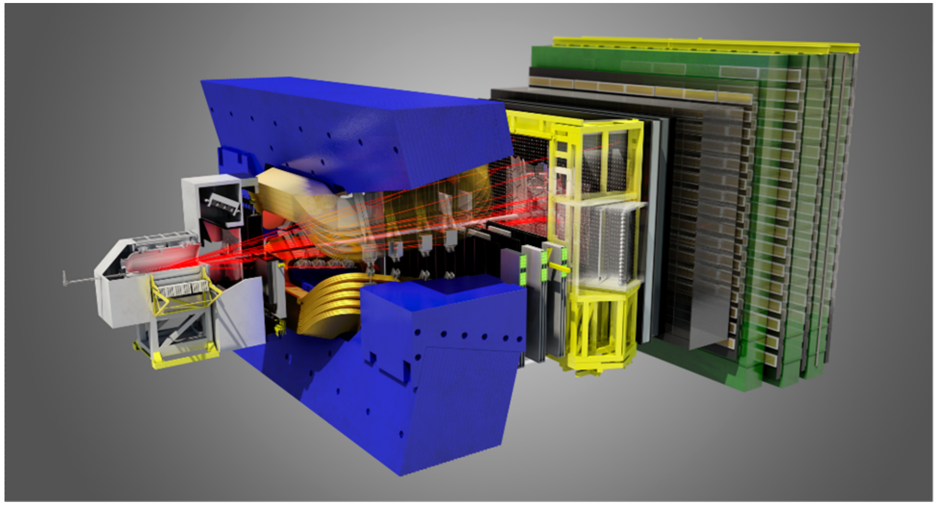
A. Bertolin on behalf of the LHCb collaboration

Outlook:

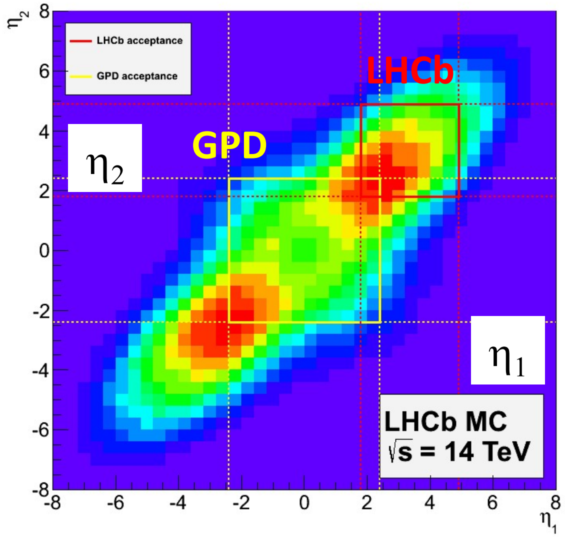
- short introduction to LHCb and γ
- LHCb γ results:
  - the LHCb γ combination
  - some recent measurements not yet included in the LHCb γ combination
- take home message and future prospects

LHCb: the detector and its performances

single-arm forward spectrometer at the LHC



b anti-b pairs produced



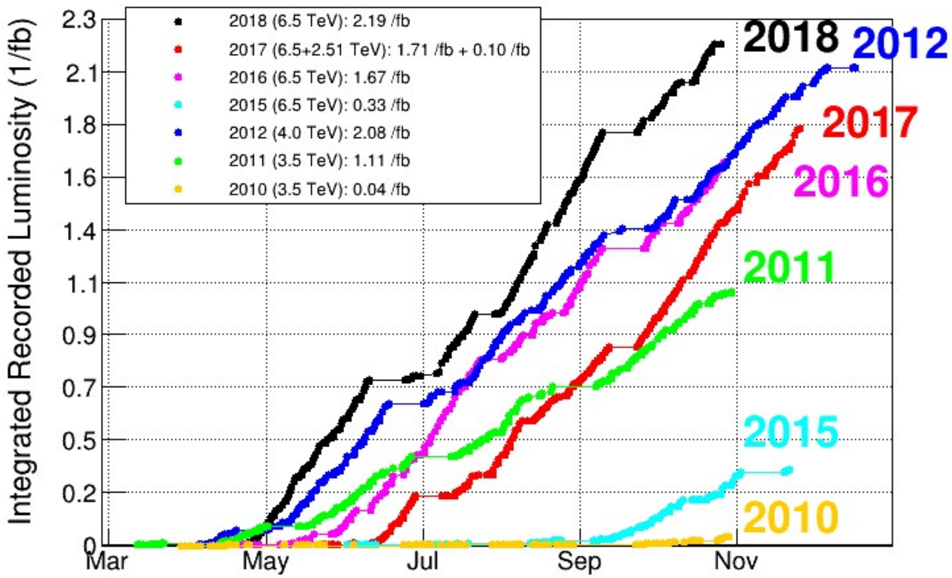
- detector paper: JINST 3 (2008) S08005
- Run 1 performance: Int. J. Mod. Phys. A30 (2015) 1530022
- Run 2 performance: JINST 14 (2019) P04013

optimized for beauty and charm physics at $2 < \eta < 5$

key points:

- momentum resolution
  ($\sigma(p)/p \approx 0.5$ % (low momentum) to 1 % @ 200 GeV/c)
- impact parameter resolution
  ($\sigma(IP) \approx 15$ μm at high p_T)
- primary and secondary vertices reco.
- decay time resolution ($\sigma(t) \approx 50$ fs)
- 'global' PID: e / μ / π / K
  (K id $\approx$ 95 % π mis-id $\approx$ 5 %, p < 100 GeV/c)
- γ and π^0 reconstruction

recorded lumi.:
2011 → 2012 (Run 1): 3 /fb
2015 → 2018 (Run 2): 6 /fb



CP violation in the SM

CP violation is one of the requirements to explain the baryon asymmetry we observe today

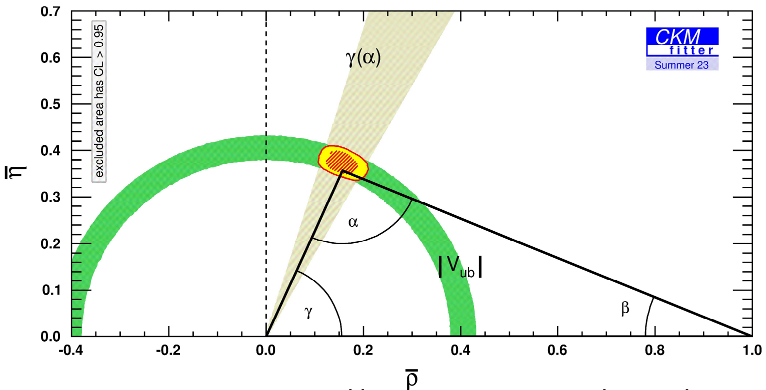
a process must have been in place that took us from the equal amounts of matter - anti-matter produced in the Big Bang to the Universe dominated by matter we are living in

the SM charged current weak interactions between quarks are described by the Cabibbo-Kobayashi-Maskawa matrix V, 3 x 3, with V V* = I ⇔ 3 angles and 1 phase or 3 reals and **1 imaginary** parameters

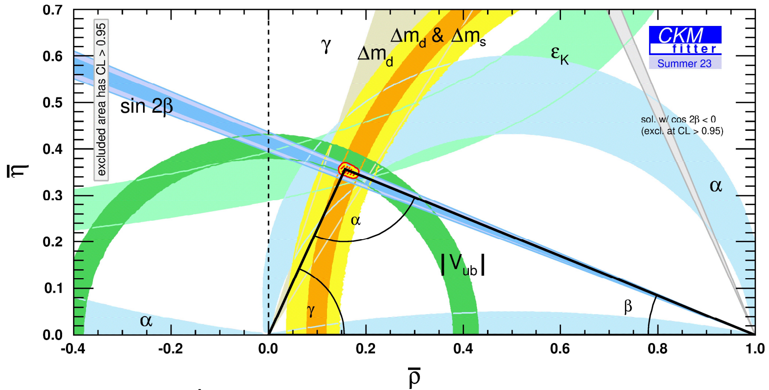
$$V_{ud}V_{ub}^{*}+V_{cd}V_{cb}^{*}+V_{td}V_{tb}^{*}=0$$

unitary condition relevant for beauty decays can be represented by a triangle in a complex plane, with angles α, β and γ

tree processes only



global analysis



http://ckmfitter.in2p3.fr/www/results/plots_summer23/ckm_res_summer23.html

$$\gamma \equiv \arg\left[-\frac{V_{ud}V^{*}_{ub}}{V_{cd}V^{*}_{cb}}\right]$$

a.k.a. ϕ_3

- only CKM angle easily accessible in tree-level decays
- assuming no new physics in tree-level decays, has negligible theoretical uncertainty i.e. achievable accuracy dominated by experiments [JHEP01(2014)051]

any disagreement between tree-level determinations and the value inferred from global CKM fits would indicate physics beyond the SM … due for example to new particles / mediators being exchanged in loops …

how to measure γ

LHCb-CONF-2022-003
JHEP12(2021)141

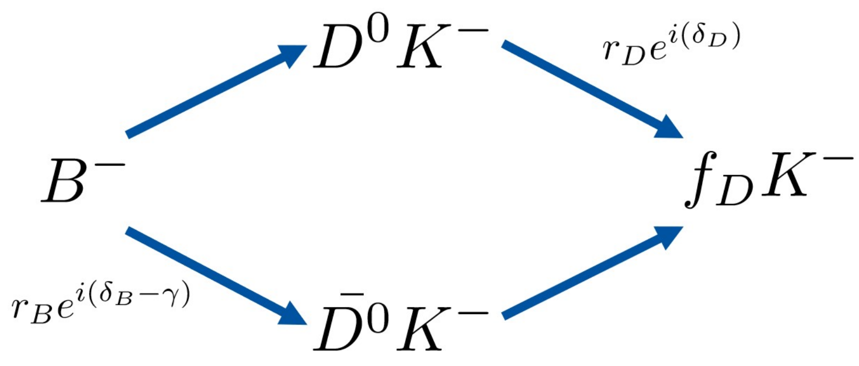
γ can be determined by exploiting the interference between
- $b \to cW$ (V_{cb}), favoured
- $b \to uW$ (V_{ub}), suppressed

transition amplitudes

$$A_{sup}/A_{fav} = r^X_B \, e^{i(\delta^X_B \pm \gamma)}$$ (– is for b-quark, + for anti-b)

where r^X_B and δ^X_B are the ratio and the strong phase differences between the V_{cb} and V_{ub} transition amplitudes for the specific final state X
these are also simultaneously determined

charm parameters can also get involved



golden mode for
illustration purposes

❑ which/typical B meson final states (h=K,π) ?

$B^+ \to D h^+$
$B^+ \to D h^+ \pi^- \pi^+$
$B^0 \to D K^{*0}$
$B^0 \to D K^+ \pi^-$

where D is a neutral charm meson mixture of the D^0 anti-D^0 flavor eigenstates

❑ which/typical D meson final states ?

- CP-eigenstates, $D \to K^+ K^-$ and $D \to \pi^+ \pi^-$: GLW method [Phys. Lett. B265 (1991) 172, Phys. Lett. B253 (1991) 483]
- non CP-eigenstates, $D^0 \to \pi^- K^+$: ADS method [Phys. Rev. D63 (2001) 036005]
- self-conjugate multibody D meson decay, like $K^0_s \pi^+ \pi^-$, with the D-Dalitz plot distributions: BPGGSZ method [Phys. Rev. D 68, 054018 (2003), Eur. Phys. J. C 47, 347 (2006)]

GLW = M. Gronau, D. London and D. Wyler
ADS = D. Atwood, I. Dunietz and A. Soni
BPGGSZ = A. Bondar, A. Poluektov, A. Giri, Y. Grossman, A. Soffer, J. Zupan

however due to the small branching ratios the most precise determination is obtained from a combination of measurements from many decay modes

LHCb γ combination

LHCb-CONF-2022-003

measurements used in the combination, the ones denoted by (*) include only a fraction of the Run 2 sample

B decay	D decay	Ref.	Dataset	Status since Ref. [14]
$B^{\pm} \to Dh^{\pm}$	$D \to h^+h^-$	[29]	Run 1&2	As before
$B^{\pm} \to Dh^{\pm}$	$D \to h^+\pi^-\pi^+\pi^-$	[30]	Run 1	As before
$B^{\pm} \to Dh^{\pm}$	$D \to K^{\pm}\pi^{\mp}\pi^+\pi^-$	[18]	Run 1&2	**New**
$B^{\pm} \to Dh^{\pm}$	$D \to h^+h^-\pi^0$	[19]	Run 1&2	**Updated**
$B^{\pm} \to Dh^{\pm}$	$D \to K^0_S h^+h^-$	[31]	Run 1&2	As before
$B^{\pm} \to Dh^{\pm}$	$D \to K^0_S K^{\pm}\pi^{\mp}$	[32]	Run 1&2	As before
$B^{\pm} \to D^*h^{\pm}$	$D \to h^+h^-$	[29]	Run 1&2	As before
$B^{\pm} \to DK^{*\pm}$	$D \to h^+h^-$	[33]	Run 1&2(*)	As before
$B^{\pm} \to DK^{*\pm}$	$D \to h^+\pi^-\pi^+\pi^-$	[33]	Run 1&2(*)	As before
$B^{\pm} \to Dh^{\pm}\pi^+\pi^-$	$D \to h^+h^-$	[34]	Run 1	As before
$B^0 \to DK^{*0}$	$D \to h^+h^-$	[35]	Run 1&2(*)	As before
$B^0 \to DK^{*0}$	$D \to h^+\pi^-\pi^+\pi^-$	[35]	Run 1&2(*)	As before
$B^0 \to DK^{*0}$	$D \to K^0_S\pi^+\pi^-$	[36]	Run 1	As before
$B^0 \to D^{\mp}\pi^{\pm}$	$D^+ \to K^-\pi^+\pi^+$	[37]	Run 1	As before
$B^0_s \to D_s^{\mp}K^{\pm}$	$D_s^+ \to h^+h^-\pi^+$	[38]	Run 1	As before
$B^0_s \to D_s^{\mp}K^{\pm}\pi^+\pi^-$	$D_s^+ \to h^+h^-\pi^+$	[39]	Run 1&2	As before
D decay	**Observable(s)**	**Ref.**	**Dataset**	**Status since Ref. [14]**
$D^0 \to h^+h^-$	ΔA_{CP}	[24, 40, 41]	Run 1&2	As before
$D^0 \to K^+K^-$	$A_{CP}(K^+K^-)$	[16, 24, 25]	Run 2	**New**
$D^0 \to h^+h^-$	$y_{CP} - y_{CP}^{K^-\pi^+}$	[42]	Run 1	As before
$D^0 \to h^+h^-$	$y_{CP} - y_{CP}^{K^-\pi^+}$	[15]	Run 2	**New**
$D^0 \to h^+h^-$	ΔY	[43–46]	Run 1&2	As before
$D^0 \to K^+\pi^-$ (Single Tag)	$R^{\pm}$, $(x'^{\pm})^2$, $y'^{\pm}$	[47]	Run 1	As before
$D^0 \to K^+\pi^-$ (Double Tag)	$R^{\pm}$, $(x'^{\pm})^2$, $y'^{\pm}$	[48]	Run 1&2(*)	As before
$D^0 \to K^{\pm}\pi^{\mp}\pi^+\pi^-$	$(x^2+y^2)/4$	[49]	Run 1	As before
$D^0 \to K^0_S\pi^+\pi^-$	x, y	[50]	Run 1	As before
$D^0 \to K^0_S\pi^+\pi^-$	x_{CP}, y_{CP}, Δx, Δy	[51]	Run 1	As before
$D^0 \to K^0_S\pi^+\pi^-$	x_{CP}, y_{CP}, Δx, Δy	[52]	Run 2	As before
$D^0 \to K^0_S\pi^+\pi^-$ (μ^- tag)	x_{CP}, y_{CP}, Δx, Δy	[17]	Run 2	**New**

inputs from the charm system

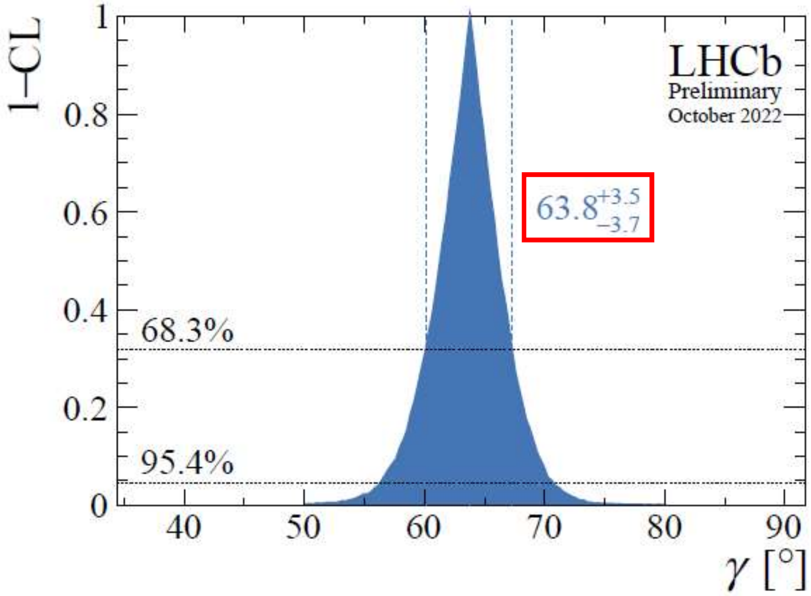
• with so many inputs it is easy to probe the stability / strength of the final result on γ

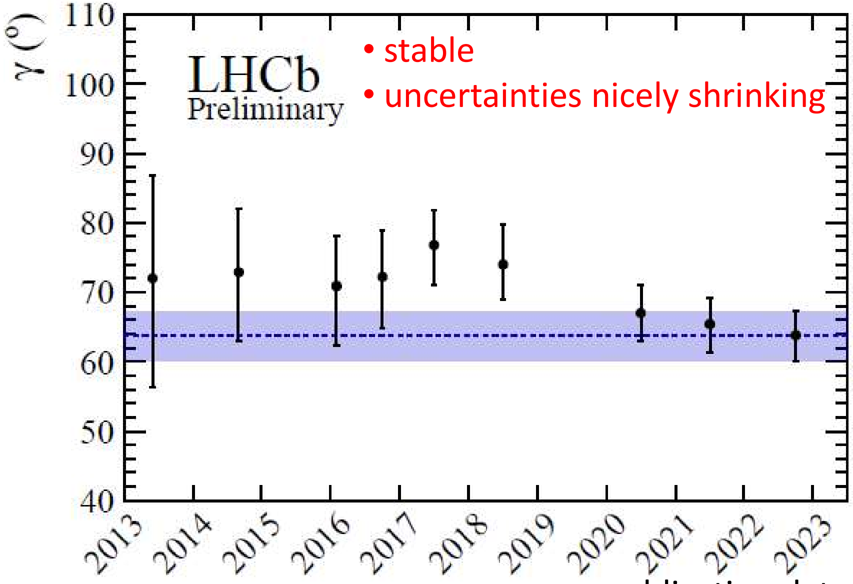
LHCb γ combination: results

LHCb-CONF-2022-003

Simultaneous determination of the CKM angle γ and parameters related to mixing and CP violation in the charm sector

- 173 input observables
- 52 free parameters
- fit quality:
  - given the χ^2 value at the best fit point and the n.d.f. the fit probability is about 80 %
  - cross checked with pseudoexperiments
- fit results: γ, common free parameter, (r_B , δ_B) for every “B”, **charm mixing parameters x and y** and a few other floated parameters





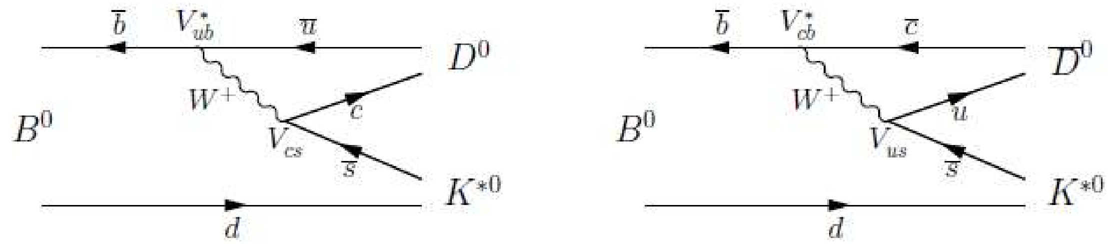
- most precise determination from a single experiment

$$x = (0.398\,^{+0.050}_{-0.049})\% \qquad y = (0.636\,^{+0.020}_{-0.019})\%$$

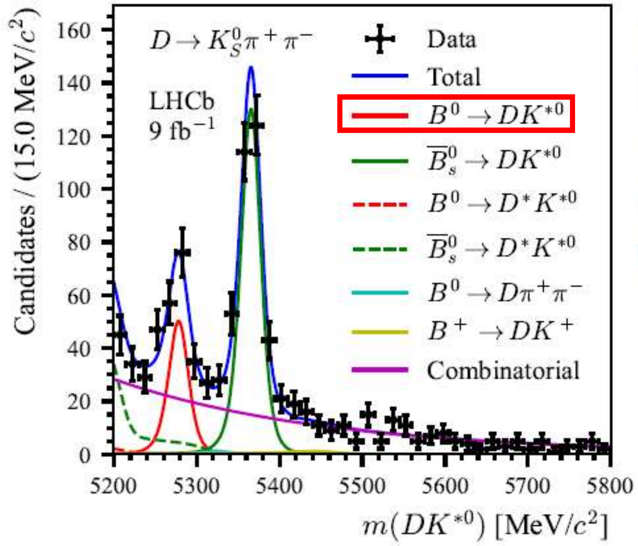
most precise determinations to date, these were taken as auxiliary inputs from HFLAV before the 2021 measurement

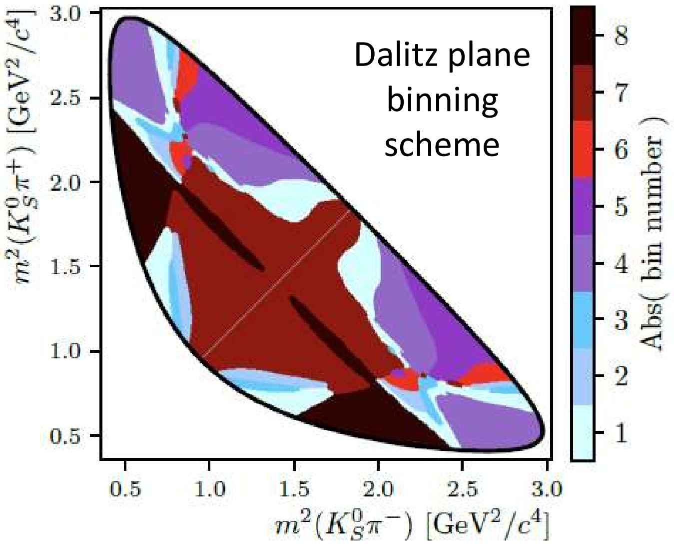
LHCb γ combination: $B^0 \to D K^{*0}$ using self-conjugate $D \to K^0_s h^+ h^-$ decays

Eur. Phys. J. C 84 (2024) 206



- $B^0 \to D K^*(892)^0$ has a lower BF wrt $B^\pm \to D K^\pm$ that has the largest impact on γ
- but the interference between the $b \to c$ favored and $b \to u$ suppressed amplitudes is expected to be a factor of 3 larger
- $D \to K^0_s h^+ h^-$ with h = {π, K}
- the flavor of the B meson at the point of decay is unambiguously provided by the charge of the kaon from the $K^*(892)^0 \to K^+\pi^-$ decay



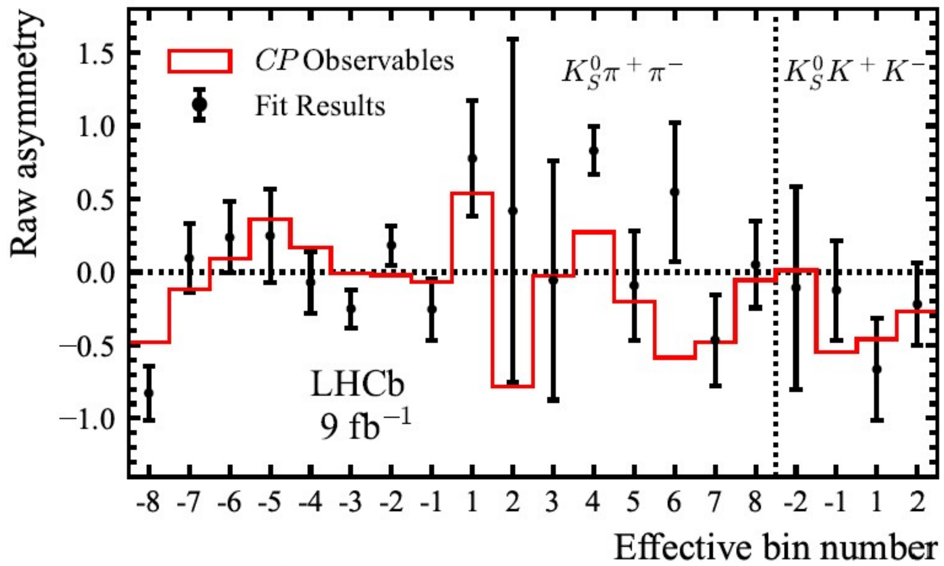


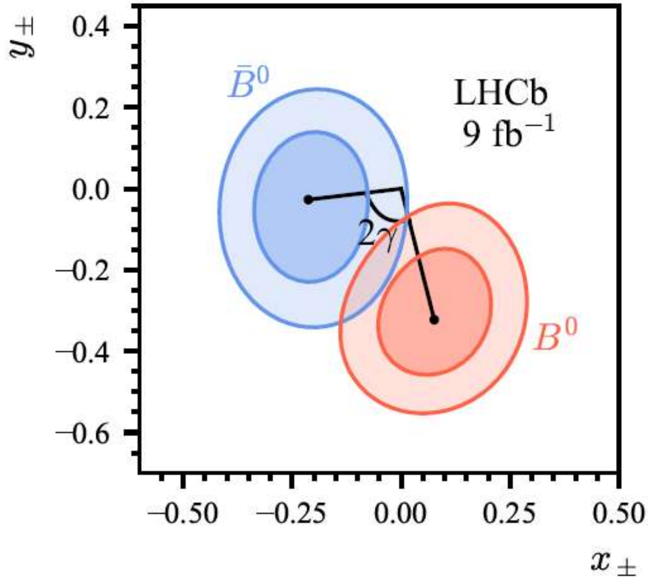
$$x_\pm \equiv r_{B^0} \cos(\delta_{B^0} \pm \gamma)$$
$$y_\pm \equiv r_{B^0} \sin(\delta_{B^0} \pm \gamma)$$
$$N_i(B^0) = h^{B^0} \left[F_{-i} + (x_+^2 + y_+^2) F_i + 2\kappa\sqrt{F_i F_{-i}} (x_+ c_i - y_+ s_i) \right]$$
$$N_i(\overline{B}^0) = h^{\overline{B}^0} \left[F_i + (x_-^2 + y_-^2) F_{-i} + 2\kappa\sqrt{F_i F_{-i}} (x_- c_i + y_- s_i) \right]$$

- i: bin in the Dalitz plot for the D decay
- F_i: fractional D0 yield in bin i, from $B^\pm \to D \pi^\pm$, $D \to K^0_s h^+ h^-$ data
- c_i and s_i are the cosine and sine of the strong-phase difference between the D0 and anti-D0 decays, from BESIII and CLEO data
- κ coherence factor diluting the interference term, fixed from data

LHCb γ combination: $B^0 \to D K^{*0}$ using self-conjugate $D \to K^0_s h^+ h^-$ decays

Eur. Phys. J. C 84 (2024) 206





$$\gamma = (49^{+22}_{-19})^\circ$$
$$r_{B^0} = 0.271^{+0.065}_{-0.066}$$

↕

$$r_B^{DK} = 0.0964 \pm 0.0028$$

JHEP04(2021)081

- result consistent with the LHCb γ combo average [LHCb-CONF-2022-003]
- confirmation of the large value of the amplitudes ratio r
- external strong phase inputs from the BESIII and CLEO collaborations are not limiting the accuracy of the measurement
- the measurement is dominated by statistical uncertainties as LHCb systematics are about 1/10 of the statistical uncertainty

→ expect improved accuracy from Run 3 data

LHCb γ combination: $B^0 \rightarrow D\,K^{*0}$ using two- and four-body D decays

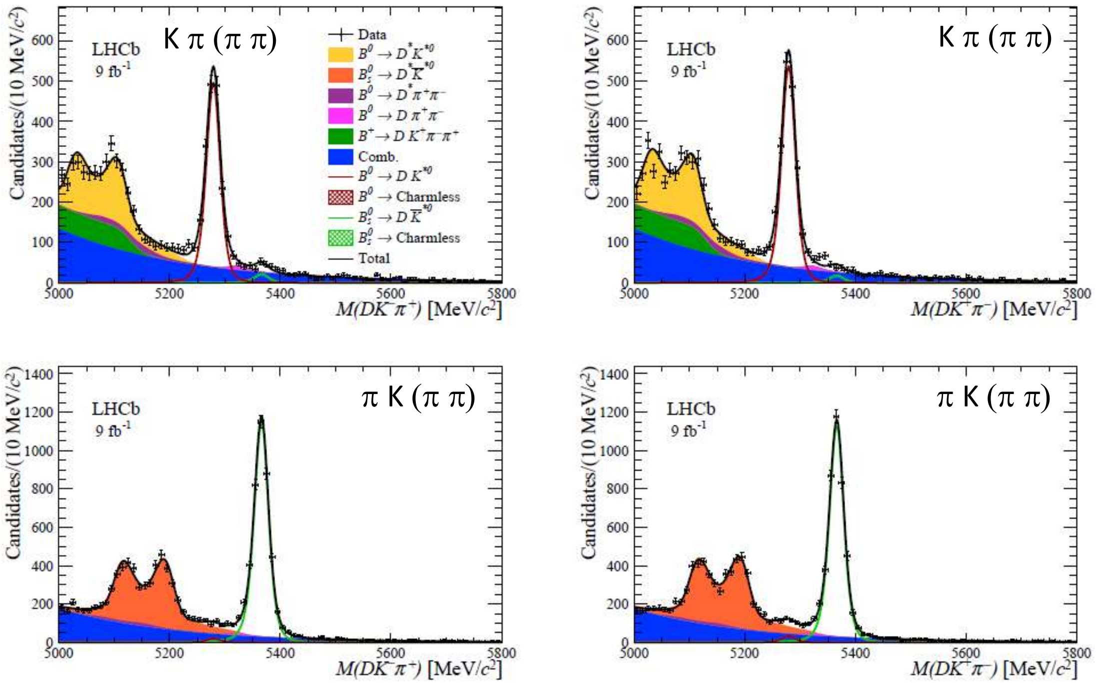
LHCb-PAPER-2023-040
https://arxiv.org/pdf/2401.17934.pdf

- interference in the admixture of Cabibbo-favored (D0) $K^- \pi^+ \pi^+ \pi^-$ and doubly Cabibbo-suppressed (antiD0) $K^- \pi^+ \pi^+ \pi^-$ decays (ADS method)
- the charge of the kaon child from the K^{*0} candidate is used to determine the flavor of the parent B meson
- $K\,\pi\,(\pi\,\pi)\,K^{*0} \equiv$ kaon child of the D candidate has the same charge as the kaon child of the K^{*0} candidate
- $\pi\,K\,(\pi\,\pi)\,K^{*0} \equiv$ the two kaons have opposite charge
- definitions of some observables:

$$\mathcal{R}^{+}_{\pi K(\pi\pi)} \equiv \frac{\Gamma\left(B^0 \to D\left[\pi K(\pi\pi)\right] K^{*0}\right)}{\Gamma\left(B^0 \to D\left[K\pi(\pi\pi)\right] K^{*0}\right)} \qquad \mathcal{R}^{-}_{\pi K(\pi\pi)} \equiv \frac{\Gamma\left(\overline{B}^0 \to D\left[\pi K(\pi\pi)\right] \overline{K}^{*0}\right)}{\Gamma\left(\overline{B}^0 \to D\left[K\pi(\pi\pi)\right] \overline{K}^{*0}\right)}$$

$$\mathcal{A}_{K\pi} \equiv \frac{\Gamma\left(\overline{B}^0 \to D[K\pi(\pi\pi)]\overline{K}^{*0}\right) - \Gamma\left(B^0 \to D[K\pi(\pi\pi)]K^{*0}\right)}{\Gamma\left(\overline{B}^0 \to D[K\pi(\pi\pi)]\overline{K}^{*0}\right) + \Gamma\left(B^0 \to D[K\pi(\pi\pi)]K^{*0}\right)}$$

cancellation of a large number of systematic uncertainties related to the reconstruction and selection of the signal candidates



for illustration purposes, the dependence of one of the observables on r γ and δ is:

$$\mathcal{R}^{\pm}_{\pi K(\pi\pi)} = \frac{\left(r_{B^0}^{DK^*}\right)^2 + \left(r_D^{K\pi(\pi\pi)}\right)^2 + 2\kappa_{B^0} r_{B^0}^{DK^*} r_D^{K\pi(\pi\pi)} \kappa_D^{K\pi(\pi\pi)} \cos\left(\delta_{B^0}^{DK^*} + \delta_D^{K\pi(\pi\pi)} \pm \gamma\right)}{1 + \left(r_{B^0}^{DK^*}\right)^2 \left(r_D^{K\pi(\pi\pi)}\right)^2 + 2\kappa_{B^0} r_{B^0}^{DK^*} r_D^{K\pi(\pi\pi)} \kappa_D^{K\pi(\pi\pi)} \cos\left(\delta_{B^0}^{DK^*} - \delta_D^{K\pi(\pi\pi)} \pm \gamma\right)}$$

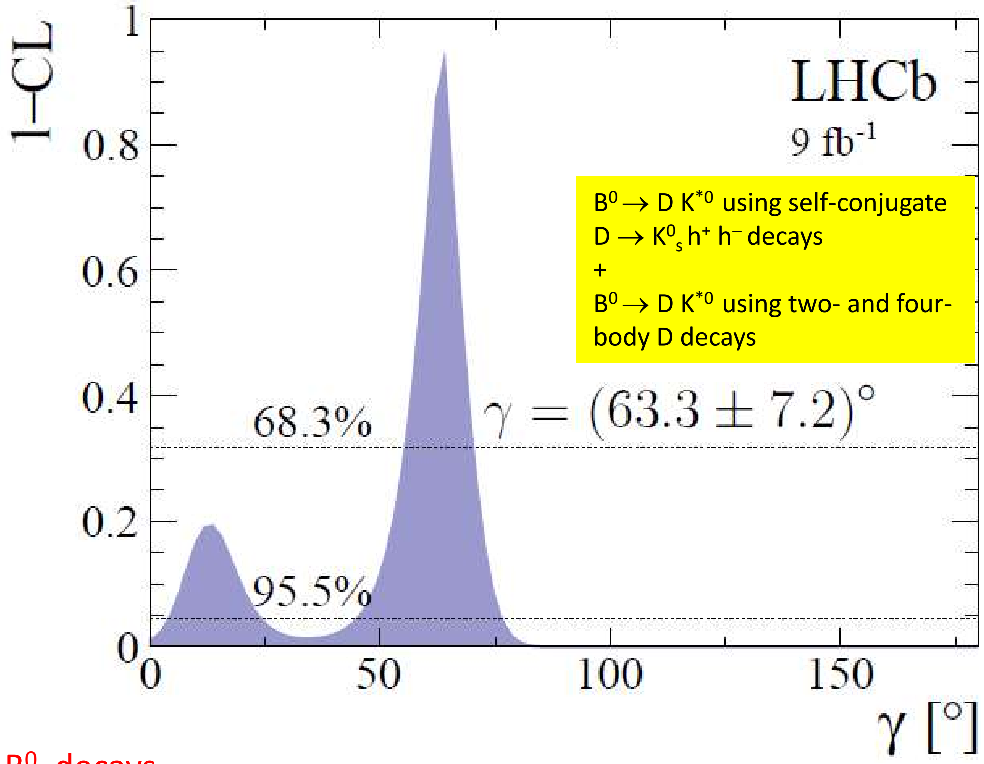
fundamental parameters of interest plus some additional inputs

additional final states are included:
- CP eigenstates $D \rightarrow K^+ K^-$ and $D \rightarrow \pi^+ \pi^-$ (GLW method)
- $D \rightarrow \pi^+ \pi^- \pi^+ \pi^-$ (mostly CP even, extension of the GLW method)
- similar observables

LHCb γ combination: $B^0 \to D K^{*0}$ using two- and four-body D decays

LHCb-PAPER-2023-040
https://arxiv.org/pdf/2401.17934.pdf

	Parameter	Value
four-body (ADS method)	$\mathcal{A}_{K\pi}$	$0.031 \pm 0.017 \pm 0.015$
	$\mathcal{R}^{+}_{\pi K}$	$0.069 \pm 0.013 \pm 0.005$
	$\mathcal{R}^{-}_{\pi K}$	$0.093 \pm 0.013 \pm 0.005$
	$\mathcal{A}_{K\pi\pi\pi}$	$-0.012 \pm 0.018 \pm 0.016$
	$\mathcal{R}^{+}_{\pi K\pi\pi}$	$0.060 \pm 0.014 \pm 0.006$
	$\mathcal{R}^{-}_{\pi K\pi\pi}$	$0.038 \pm 0.014 \pm 0.006$
two-body CP eigenstates (GLW method)	$\mathcal{R}^{KK}_{CP}$	$0.811 \pm 0.057 \pm 0.017$
	$\mathcal{A}^{KK}_{CP}$	$-0.047 \pm 0.063 \pm 0.015$
	$\mathcal{R}^{\pi\pi}_{CP}$	$1.104 \pm 0.111 \pm 0.026$
	$\mathcal{A}^{\pi\pi}_{CP}$	$-0.034 \pm 0.094 \pm 0.016$
four-body mostly CP even (extended GLW method)	$\mathcal{R}^{4\pi}_{CP}$	$0.882 \pm 0.086 \pm 0.033$
	$\mathcal{A}^{4\pi}_{CP}$	$0.021 \pm 0.087 \pm 0.016$



- most stringent limits to date on γ from B^0 decays
- result is consistent with the LHCb γ combo average [LHCb-CONF-2022-003]
- for most of the observables the statistical uncertainties are dominant

$\to$ expect improved accuracy from Run 3 data

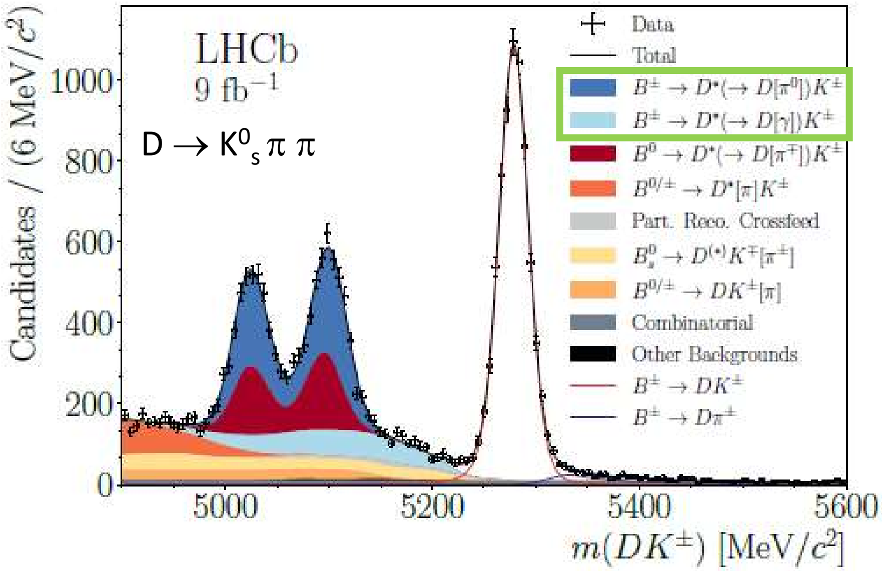
LHCb γ combination: $B^\pm \to D^* h^\pm$ with partial D* reconstruction

JHEP02(2024)118

- $B^\pm \to [D\gamma / \pi^0] h^\pm$ with partial reconstruction of the D^*, $D \to K^0_s hh$ and h = {π, K}
- the B^- decay via D0 (anti-D0) proceed with the favored (suppressed) amplitude, interference occur because the final state particles are identical

$$\mathcal{A}(B^- \to [D\pi^0]_{D^*}K^-) = \mathcal{A}_B(\mathcal{A}_D + r_B^{D^*K} \exp[i(\delta_B^{D^*K} - \gamma)]\mathcal{A}_{\overline{D}})$$

$$x_\pm^{D^*K} \equiv r_B^{D^*K} \cos(\delta_B^{D^*K} \pm \gamma) \quad \text{and} \quad y_\pm^{D^*K} \equiv r_B^{D^*K} \sin(\delta_B^{D^*K} \pm \gamma)$$



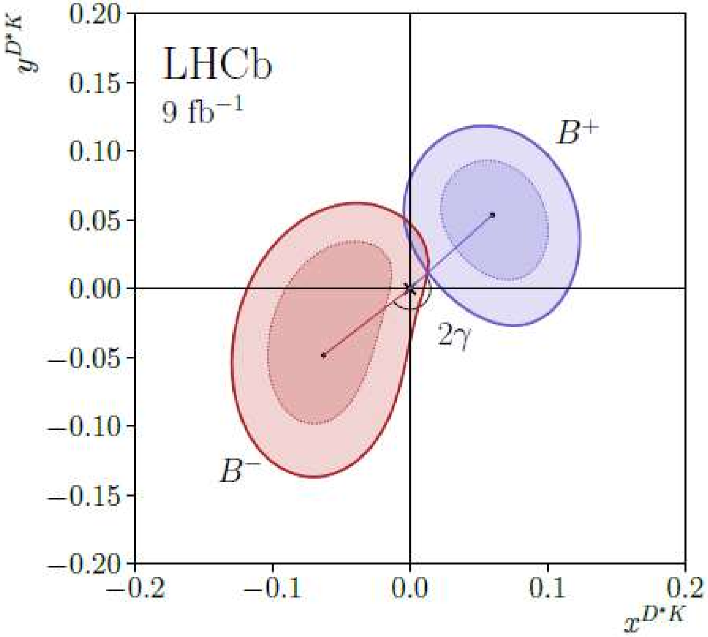
D decay	Component	Reconstructed as: $B^\pm \to DK^\pm$	$B^\pm \to D\pi^\pm$
$D \to K^0_S\pi^+\pi^-$	$B^\pm \to D^*[D\pi^0]K^\pm$	6244 ± 12	2716 ± 5
	$B^\pm \to D^*[D\pi^0]\pi^\pm$	340 ± 1	$113\,170 \pm 229$
	$B^\pm \to D^*[D\gamma]K^\pm$	3144 ± 6	1247 ± 2
	$B^\pm \to D^*[D\gamma]\pi^\pm$	166 ± 1	$60\,285 \pm 121$
	$B^\pm \to DK^\pm$	$10\,398 \pm 21$	4726 ± 9
	$B^\pm \to D\pi^\pm$	590 ± 1	$196\,804 \pm 398$
	Other backgrounds	$10\,402 \pm 105$	$206\,664 \pm 592$
	Combinatorial background	1343 ± 147	$15\,177 \pm 706$
$D \to K^0_S K^+K^-$	$B^\pm \to D^*[D\pi^0]K^\pm$	790 ± 3	344 ± 1
	$B^\pm \to D^*[D\pi^0]\pi^\pm$	43 ± 1	$14\,327 \pm 65$
	$B^\pm \to D^*[D\gamma]K^\pm$	397 ± 1	157 ± 1
	$B^\pm \to D^*[D\gamma]\pi^\pm$	21 ± 1	7636 ± 34
	$B^\pm \to DK^\pm$	1527 ± 6	694 ± 2
	$B^\pm \to D\pi^\pm$	88 ± 1	$29\,786 \pm 135$
	Other backgrounds	1573 ± 15	$31\,278 \pm 115$
	Combinatorial background	263 ± 46	4413 ± 261

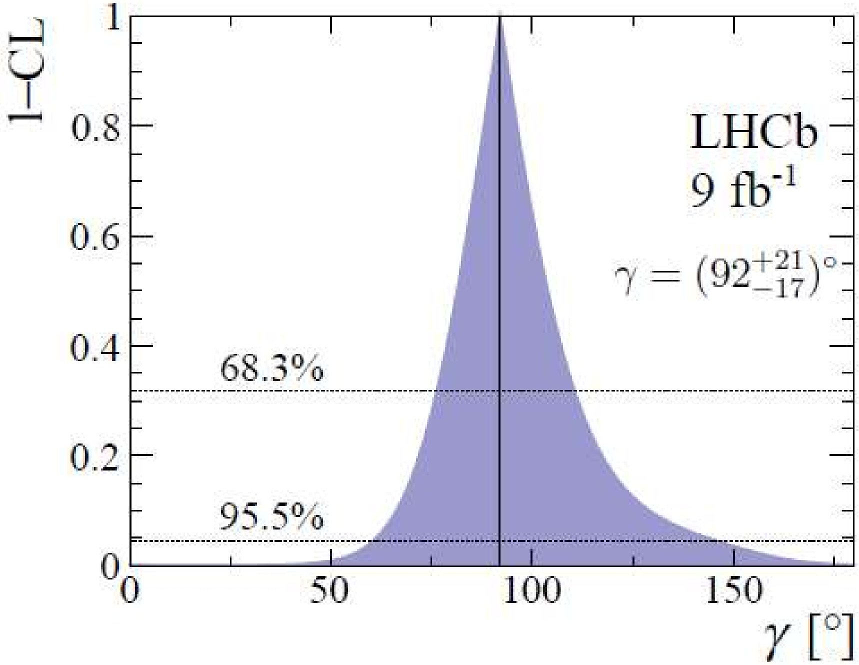
$$N_i^+ \propto [F_{-i} + (x_+^2 + y_+^2)F_{+i} + 2\kappa\sqrt{F_{-i}F_{+i}}(c_i x_+ - s_i y_+)]$$

- i: bin in the Dalitz plot for the D decay
- F_i c_i s_i and κ as in pag. 7
- **unknowns:** F_i , $x_\pm$ and $y_\pm$

LHCb γ combination: $B^{\pm} \to D^{*} h^{\pm}$ with partial D* reconstruction

JHEP02(2024)118





• result consistent with the LHCb γ combo average [LHCb-CONF-2022-003]

• given the accuracy of the BESIII and CLEO data the corresponding systematic uncertainties on $x_{\pm}$ and $y_{\pm}$ are small (< ½) compared to the LHCb systematic uncertainties

• the total systematic uncertainty is at least a factor of 2 smaller than the statistical uncertainty

$\to$ expect improved accuracy from Run 3 data

in [JHEP12(2023)013] an exclusive reconstruction of the $D^* \to D\,\gamma\,/\,\pi^0$ decay is shown followed by the extraction of γ, the same data set is being used

the signal yield is reduced by approximatively 75 %

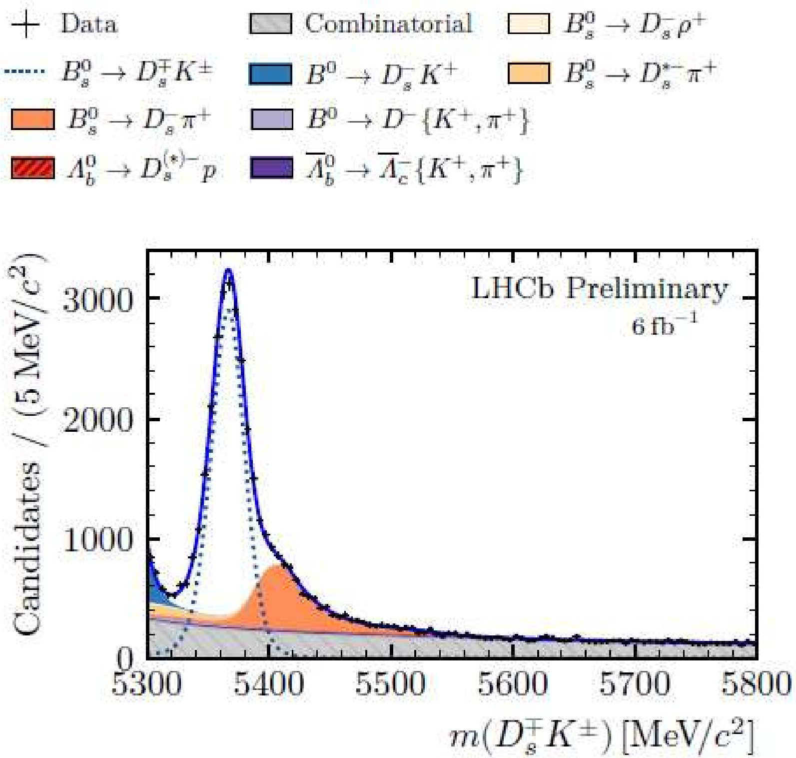
• the extracted value of γ is compatible with the value obtained from the partially reconstructed approach

• the overall uncertainty on γ is even smaller

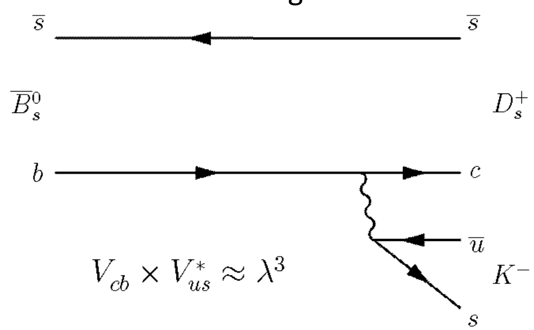
LHCb γ combination: $B^0_s \to D_s K$

LHCb-CONF-2023-004

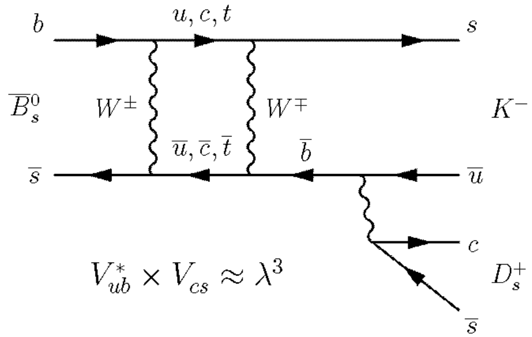
• sensitivity to γ from interference of decay amplitudes with and without mixing



without mixing



with mixing



• time dependent analysis: decay time acceptance obtained from $B_s \to D_s \pi$ DATA, corrected for the $B_s \to D_s K$ to $B_s \to D_s \pi$ MC decay time acceptance ratio (small)

• require flavor tagging

time dependent decay rates

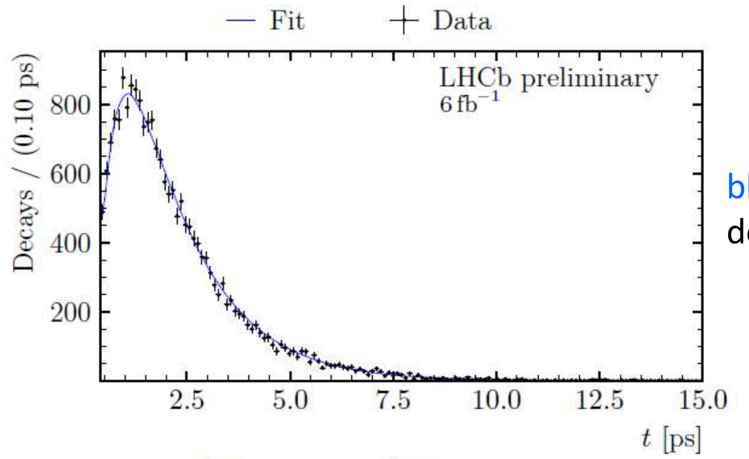
$$\frac{\mathrm{d}\Gamma_{B_s^0 \to f}(t)}{\mathrm{d}t} = \frac{1}{2}|A_f|^2 (1 + |\lambda_f|^2) e^{-\Gamma_s t} \left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta\Gamma} \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) + C_f \cos(\Delta m_s t) - S_f \sin(\Delta m_s t) \right],$$

$$\frac{\mathrm{d}\Gamma_{\overline{B}_s^0 \to f}(t)}{\mathrm{d}t} = \frac{1}{2}|A_f|^2 \left|\frac{p}{q}\right|^2 (1 + |\lambda_f|^2) e^{-\Gamma_s t} \left[\cosh\left(\frac{\Delta\Gamma_s t}{2}\right) + A_f^{\Delta\Gamma} \sinh\left(\frac{\Delta\Gamma_s t}{2}\right) - C_f \cos(\Delta m_s t) + S_f \sin(\Delta m_s t) \right]$$

CP parameters related to r_B δ_B $(\gamma - 2\beta_s)$

LHCb γ combination: $B^0_s \rightarrow D_s K$

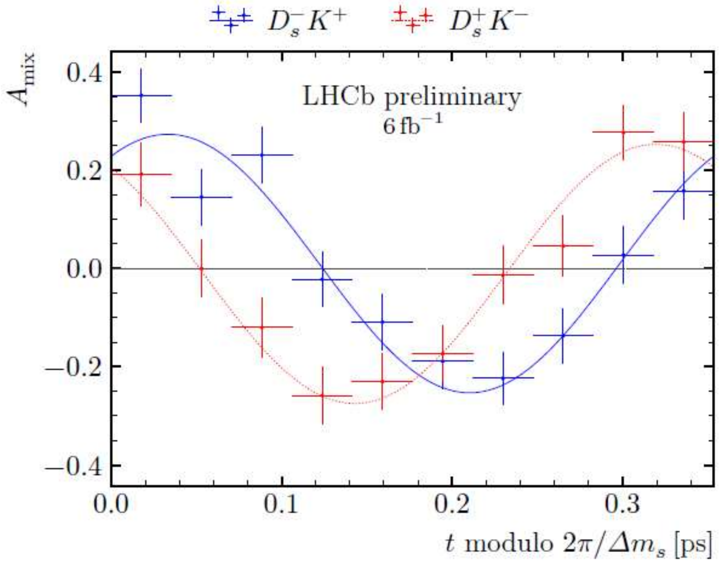
LHCb-CONF-2023-004



blue curve: fit to the decay time distribution

$$C_f = 0.791 \pm 0.061 \pm 0.022$$
$$A_f^{\Delta\Gamma} = -0.051 \pm 0.134 \pm 0.037$$
$$A_{\bar{f}}^{\Delta\Gamma} = -0.303 \pm 0.125 \pm 0.036$$
$$S_f = -0.571 \pm 0.084 \pm 0.023$$
$$S_{\bar{f}} = -0.503 \pm 0.084 \pm 0.025$$

$C_f = - C_{fbar}$
- no CPV in decay
- no CPV in mixing
- CPV only in the interference



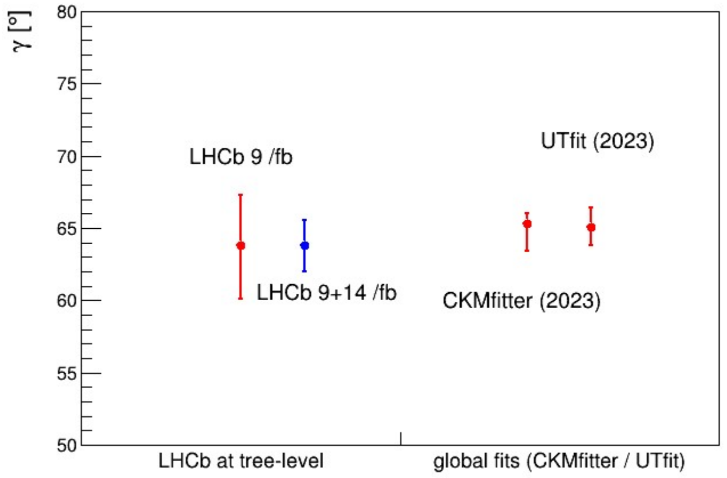
folded asymmetry plots for $D_s^+ K^-$ and $D_s^- K^+$
CP violation: non trivial phase difference for t = 0 ps

- strictly speaking probing $\gamma - 2\beta_s$, using in addition $\phi_s = -2\beta_s$ and ϕ_s from HFLAV

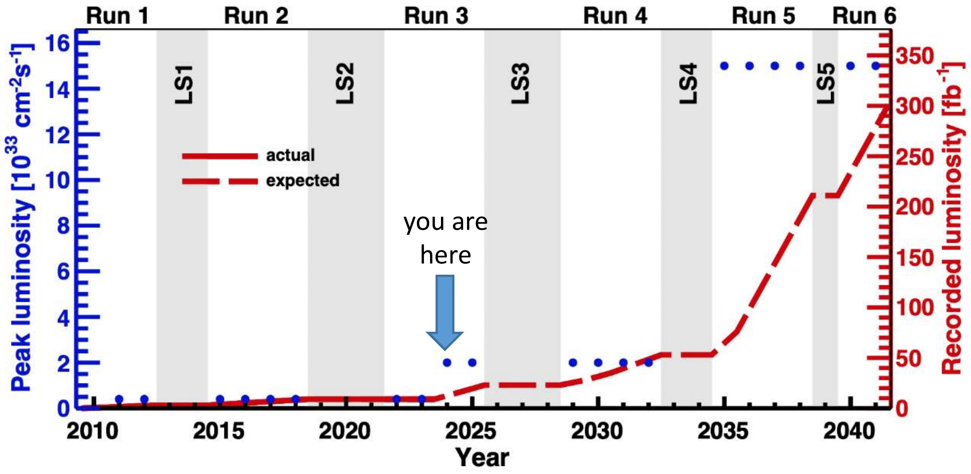
- 2011 → 2012 data (3 /fb), JHEP03 (2018) 059 $\gamma = (128^{+17}_{-22})^\circ$
- 2015 → 2018 data (6/fb), this analysis $\gamma = (74 \pm 11)^\circ$

- 2011/2012 result driven by a statistical fluctuation
- 2015/2018 result closer to other channels
- will average them

LHCb γ combination: take home message and future prospects



- 2022 LHCb γ combination based on 9 /fb: 63.8 [+3.5,-3.7]
- CKMfitter: 65.29 [+0.72 -1.86]



- > 10 input measurements that can cross check each other
- present uncertainty is not yet what we need
- "short term": 9 /fb, Run 1 + Run 2, legacy combination, needed because several recent measurement are not included in the 2021 release

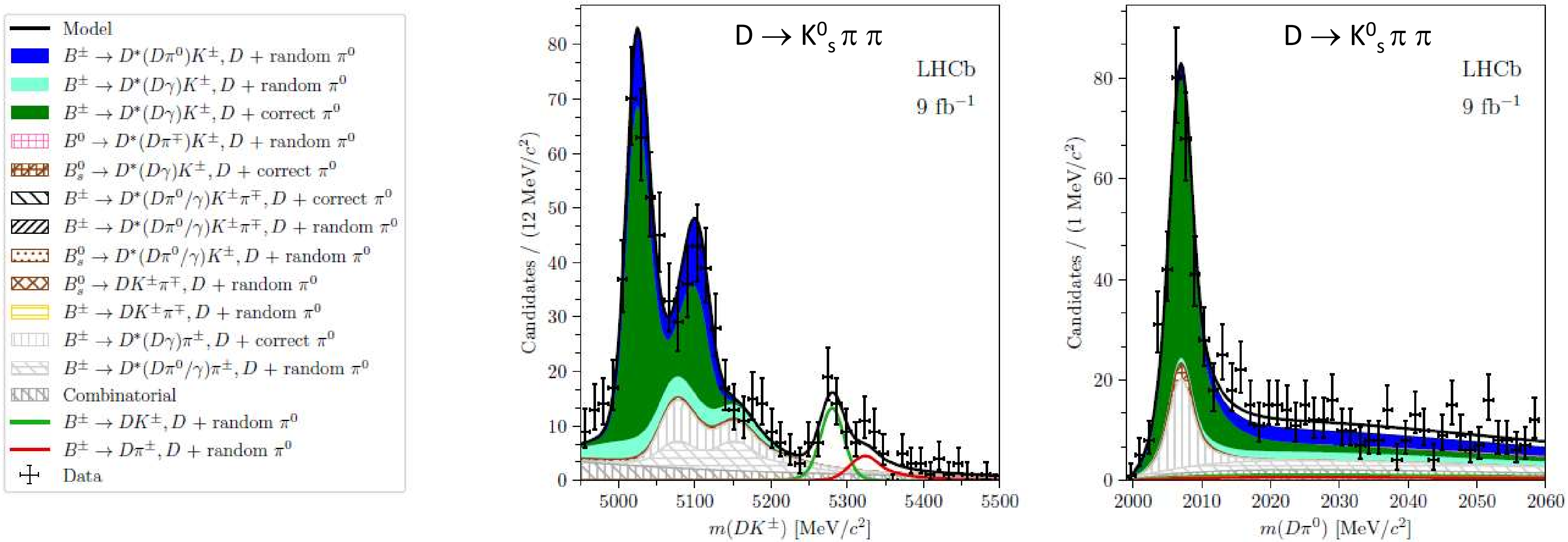
- **"longer term":**
  - The LHCb Upgrade II, Xuhao Yuan, WG6, Tuesday at 14:00
  - fresh data from 2024 on the way, 7 /fb
  - 2025 additional 7 /fb
  - with 9+14 /fb we expect an accuracy in the range 1.7 - 2.3^o
- if the accuracy of the external inputs will not limit the LHCb measurement could reach a 0.35^o uncertainty with 300 /fb

- LHCb is doing well, with very significant improvements w.r.t. BaBar and Belle, and has excellent potentialities
- Belle II will also be able to push towards a reduction of the γ uncertainty, expect the same sensitivity

Backup material

LHCb γ combination: $B^{\pm} \to D^{*} h^{\pm}$ with exclusive D* reconstruction

JHEP12(2023)013



invariant mass variables providing the best separation between signal and (many) backgrounds are:

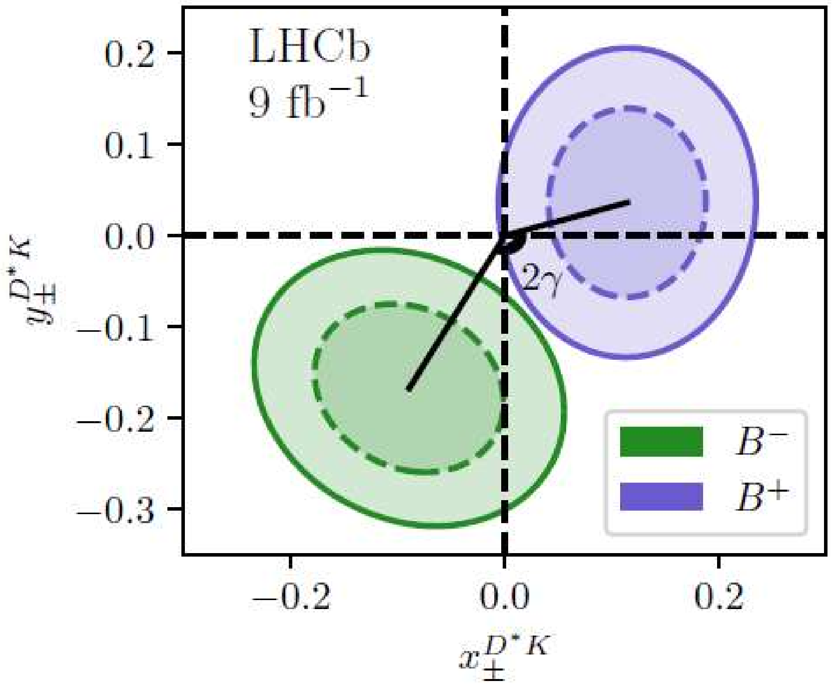
- m(Dh) h={π, K} not peaking at the B mass because the neutral is excluded
- m(Dπ^0) or m(Dγ) peaking at the nominal D* mass

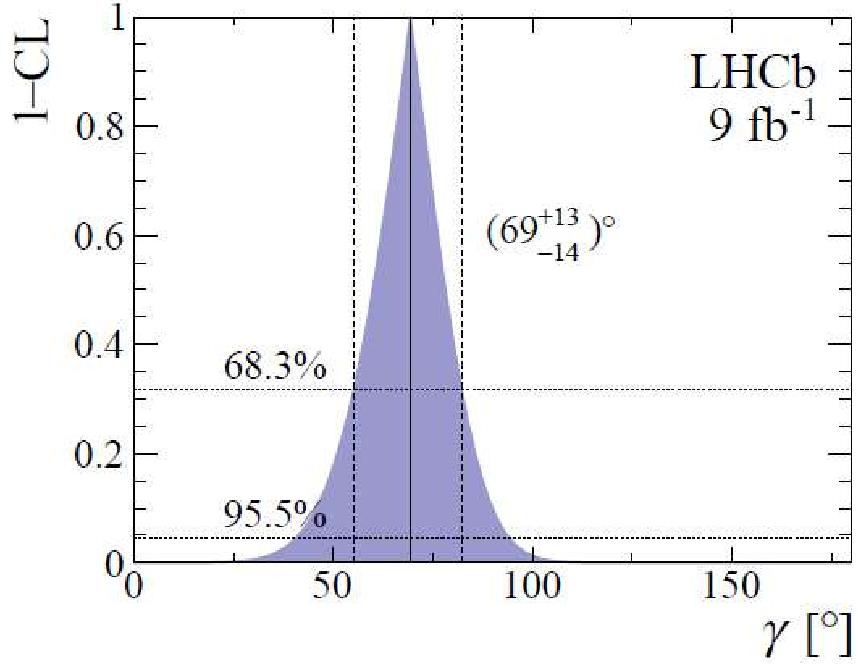
• LHCb can successfully use neutrals in a very busy hadron collider environments

Component	Yield
$B^+ \to D^*\pi^+, D^* \to D\pi^0$	199 ± 13
$B^+ \to D^*\pi^+, D^* \to D\gamma$	782 ± 49
$B^- \to D^*\pi^-, D^* \to D\pi^0$	197 ± 13
$B^- \to D^*\pi^-, D^* \to D\gamma$	740 ± 48
$B^+ \to D^*K^+, D^* \to D\pi^0$	13 ± 2
$B^+ \to D^*K^+, D^* \to D\gamma$	69 ± 11
$B^- \to D^*K^-, D^* \to D\pi^0$	13 ± 2
$B^- \to D^*K^-, D^* \to D\gamma$	57 ± 11

LHCb γ combination: $B^{\pm} \to D^{*} h^{\pm}$ with exclusive D^* reconstruction

JHEP12(2023)013





- this result is consistent with the LHCb γ combo average [LHCb-CONF-2022-003]
- and dominated by statistical uncertainties

LHCb γ combination: remark on "auxiliary" inputs

Decay	Parameters	Source	Ref.	Status since Ref. [14]
$B^\pm \to DK^{*\pm}$	$\kappa_{B^\pm}^{DK^{*\pm}}$	LHCb	[33]	As before
$B^0 \to DK^{*0}$	$\kappa_{B^0}^{DK^{*0}}$	LHCb	[53]	As before
$B^0 \to D^\mp\pi^\pm$	β	HFLAV	[13]	As before
$B_s^0 \to D_s^\mp K^\pm(\pi\pi)$	ϕ_s	HFLAV	[13]	As before
$D \to K^+\pi^-$	$\cos\delta_D^{K\pi}$, $\sin\delta_D^{K\pi}$, $(r_D^{K\pi})^2$, x^2, y	CLEO-c	[27]	New
$D \to K^+\pi^-$	$A_{K\pi}$, $A_{K\pi}^{\pi\pi\pi^0}$, $r_D^{K\pi}\cos\delta_D^{K\pi}$, $r_D^{K\pi}\sin\delta_D^{K\pi}$	BESIII	[28]	New
$D \to h^+h^-\pi^0$	$F_{\pi\pi\pi^0}^+$, $F_{KK\pi^0}^+$	CLEO-c	[54]	As before
$D \to \pi^+\pi^-\pi^+\pi^-$	$F_{4\pi}^+$	CLEO-c+BESIII	[26, 54]	**Updated**
$D \to K^+\pi^-\pi^0$	$r_D^{K\pi\pi^0}$, $\delta_D^{K\pi\pi^0}$, $\kappa_D^{K\pi\pi^0}$	CLEO-c+LHCb+BESIII	[55–57]	As before
$D \to K^\pm\pi^\mp\pi^+\pi^-$	$r_D^{K3\pi}$, $\delta_D^{K3\pi}$, $\kappa_D^{K3\pi}$	CLEO-c+LHCb+BESIII	[49, 55–57]	As before
$D \to K_S^0K^\pm\pi^\mp$	$r_D^{K_S^0K\pi}$, $\delta_D^{K_S^0K\pi}$, $\kappa_D^{K_S^0K\pi}$	CLEO	[58]	As before
$D \to K_S^0K^\pm\pi^\mp$	$r_D^{K_S^0K\pi}$	LHCb	[59]	As before

- there are some
- whenever possible these are taken from data
  - whenever possible from LHCb data !

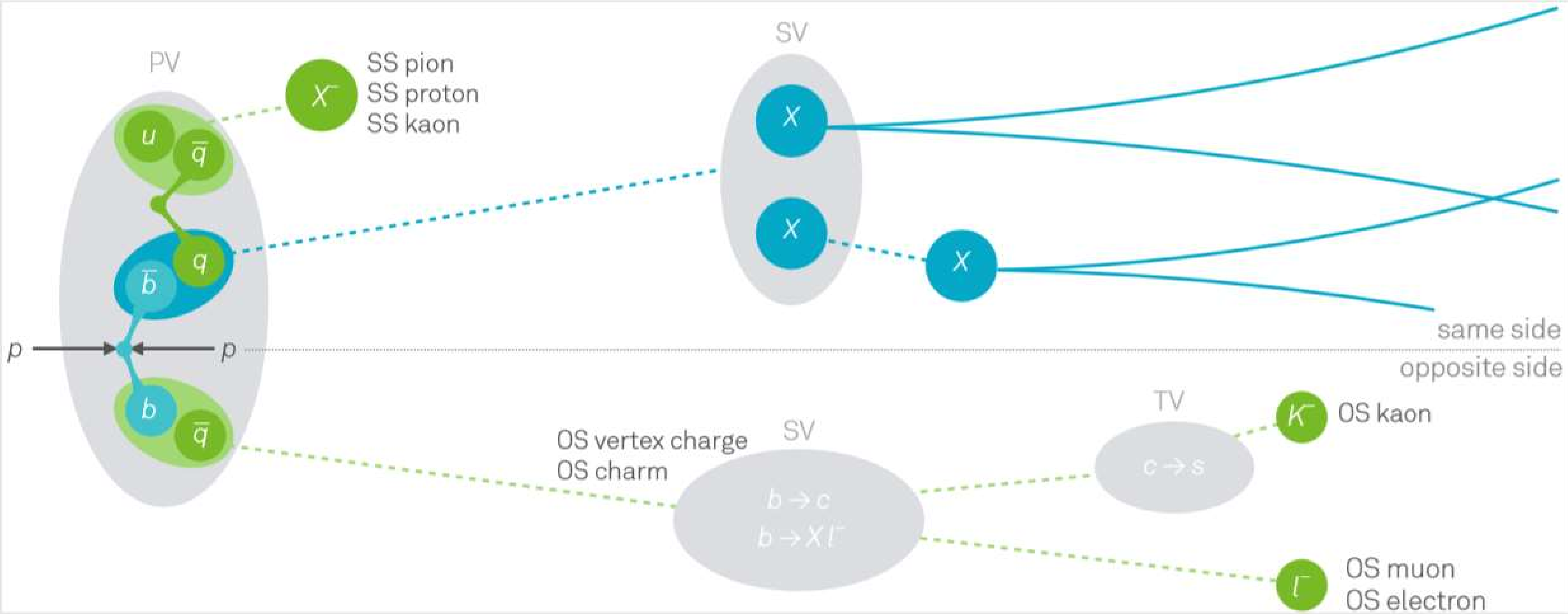
CP violation: historical approach

BaBar 2000-2008, 0.5 /ab $\gamma = (69^{+17}_{-16})^\circ$ PRD 87, 052015 (2013) “legacy paper”

2000-2010, 0.8 /ab

so this presentation will focus on LHCb results, keeping in mind that a new player is coming into the game: Belle II

Flavor tagging



Tagging performances

CERN-LHCC-2018-027 or
LHCB-PUB-2018-009 or
https://arxiv.org/abs/1808.08865